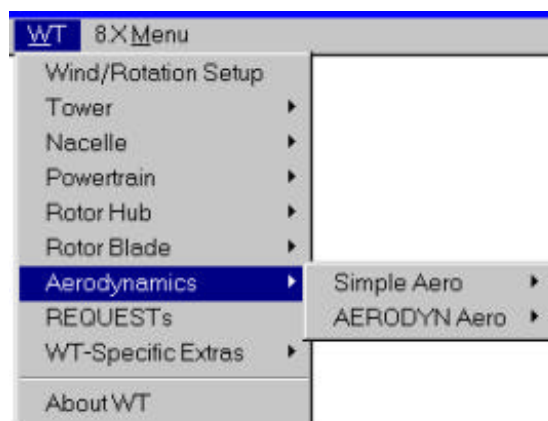


# Chapter 6 Aerodynamic Loads

As with any code for predicting wind turbine rotor aeroelastic response, generation of reasonable airloads on the blades is a very difficult and fundamental problem. The environment in which turbines generally operate can produce highly non-uniform flow with strong stochastic content. Because the scale of atmospheric turbulence at rotor height is of the same order as the rotor diameter, individual blades can be engulfed in coherent turbulence structures which cause very large responses and can severely disrupt the wake structure. Furthermore, the blade sections can see highly variable, large angle unsteady flows at large reduced frequencies, so that nonlinear and unsteady aerodynamic effects are significant. Finally, the rotor blades themselves can be very flexible and the entire system is often free in yaw and mounted at the end of a tall, flexible tower.

The core ADAMS software, as mentioned previously, is a general-purpose mechanical system simulation tool and is designed to be capable of handling any type of structural motion. Unlike many finite-element-based rotor codes, ADAMS automatically accounts for all the nonlinear inertial and geometric coupling and stiffening effects due to system motion, and automatically takes care of internal reaction loads. Generation of applied loads, however, is left to the user, with a very wide selection of available force types and definition methods.

As discussed in sections 4.4 and 4.5, ADAMS/WT includes aerodynamic loads via specially-defined action-only VFORCE or GFORCE elements that are attached to aerodynamic control points and move with the blades. Two force algorithms are offered in the 2.0 release of ADAMS/WT, a very simple force based on steady, linear aerodynamics, and a very complex definition which can include multiple airfoil sections, nonlinear and unsteady response, wind shear, tower shadow, turbulence and wake effects. Both of the algorithms work irrespective of the direction of rotation of the rotor. These airloads are attached to the blades through the AERODYNAMICS menu:



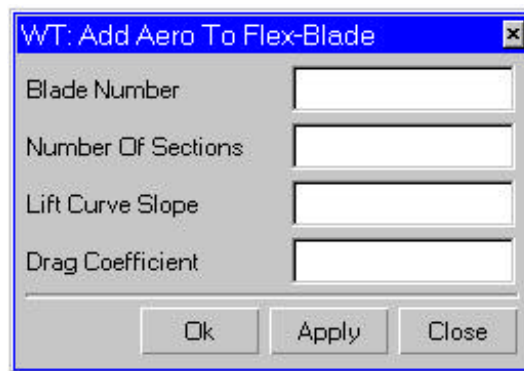
### 6.1 Simple Aerodynamics

Selecting the SIMPLE AERO button displays another menu column where you can choose between flexible and rigid blades, depending on which are in your model. Selecting either choice will display the appropriate a panel for attaching simple aerodynamic force elements to an entire blade at one time. For more information about these elements, see section 4.5.



Note that this approach assumes <sup>(1)</sup> that the wind velocity is modeled in a dummy VFORCE named *wind* (for more detail about the *wind* element, see section 4.5), <sup>(2)</sup> that the interpolated aerodynamic information generated while building the blade is still available in a file called *flexdat4.tmp*, and <sup>(3)</sup> that a user-executable version of ADAMS/Solver is available incorporating the VFOSUB code in *safsub.f*, or an equivalent.

For a flexible blade you will see this panel:



#### Blade Number

The number assigned to the blade when it was created. Automatic addition of aerodynamic forces will only work for blades created by WT.

#### Number\_of\_Sections

The number of blade parts specified when the blade was created.

#### Lift\_Curve\_Slope

The slope of the (assumed linear) lift coefficient vs. angle-of-attack curve, per radian. This is the  $(dCL/d\alpha)$  term in the equation  $CL = (dCL/d\alpha)\alpha$ .

#### Drag Coefficient

The assumed-constant profile drag coefficient,  $CD_0$ .

For a rigid blade, you would see this panel:



The image shows a Windows-style dialog box titled "WT: Add Aero To Rigid Blade". It contains several input fields for configuring aerodynamic parameters for a rigid blade. The fields are: "Blade Number", "Number Of Parts", "Lift Curve Slope", "Drag Coefficient", "Number of Aero Sections" (which is a section header), "On Part 1", and "On Part 2". At the bottom of the dialog are three buttons: "Ok", "Apply", and "Close".

### **Blade Number**

The number assigned to the blade when it was created. Automatic addition of aerodynamic forces will only work for blades created by WT.

### **Number\_of\_Parts**

The number of blade parts specified when the blade was created. Normally, this will be 2, but could be 1 for a blade without an hinge.

### **Lift\_Curve\_Slope**

The slope of the (assumed linear) lift coefficient vs. angle-of-attack curve, per radian. This is the  $(dCL/d\alpha)$  term in the equation  $CL = (dCL/d\alpha)\alpha$ .

### **Drag Coefficient**

The assumed-constant profile drag coefficient,  $CD_0$ .

### **Number of Aero Sections on Part 1**

The number of aerodynamic sections specified for the inboard blade PART when the blade was created.

### **Number of Aero Sections on Part 2**

The number of aerodynamic sections specified for the outboard blade PART when the blade was created. If the blade has only one part, it is this one.

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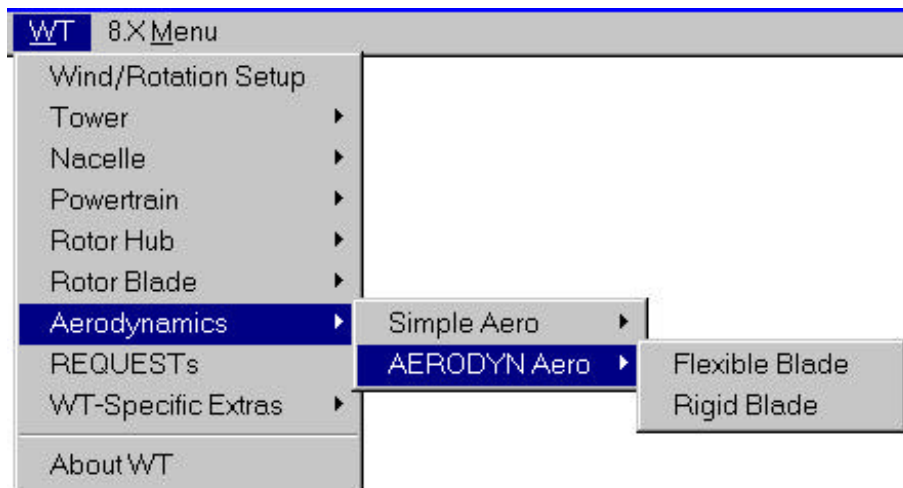
Executing either of these panels will generate VFORCE simple aerodynamic force elements (and their associated velocity VARIABLES, see section 4.4) all along the selected blade at the aerodynamic center markers. Each VFORCE will have the correct parameter list for the standard VFOSUB. Note that, by default, the effect of induced inflow is not included. You may choose to add induced inflow manually (see section 6.3).

### 6.2 AeroDyn (Utah) Aerodynamics

Selecting the AERODYN AERO button displays another menu column where you can choose between flexible and rigid blades, depending on which are in your model. Selecting either choice will display the appropriate a panel for attaching aerodynamic force elements based on the AeroDyn routines to an entire blade at one time. For more information about these elements, see appendix H, the AeroDyn User's Manual. Note that support for AeroDyn is supplied by the University of Utah, not MDI. For detailed questions about AeroDyn, contact:

Dr. A. Craig Hansen  
Mechanical Engineering Department  
University of Utah  
Salt Lake City, UT 84112  
801/581-4145  
hansen@me.mech.utah.edu

The AeroDyn choices look like:



This approach assumes <sup>(1)</sup> that the interpolated aerodynamic information used to build the blade still available in a file called *flexdat4.tmp*, and <sup>(2)</sup> that a user-executable version of ADAMS/Solver is available incorporating the AeroDyn subroutine package. All effects of wind, shear, shadow, etc. are accounted for internally to AeroDyn.

For the flexible blade, you should get this input panel:



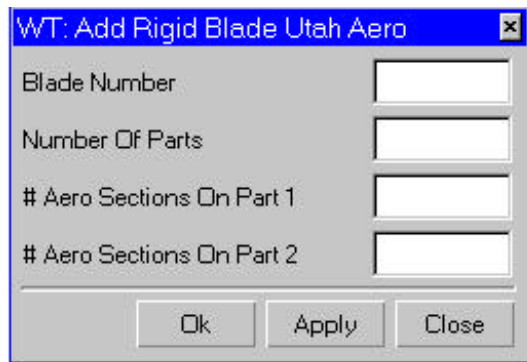
### **Blade Number**

The number assigned to the blade when it was created. Automatic addition of aerodynamic forces will only work for blades created by WT.

### **Number\_of\_Sections**

The number of blade parts specified when the blade was created.

For the rigid blade, you should get this panel:



### **Blade Number**

The number assigned to the blade when it was created. Automatic addition of aerodynamic forces will only work for blades created by WT.

### **Number\_of\_Sections**

The number of blade parts specified when the blade was created. Normally, this will be 2, but could be 1 for a blade without an hinge.

### **# Aero Sections on Part 1**

The number of aerodynamic sections specified for the inboard blade PART when the blade was created.

### # Aero Sections on Part 2

The number of aerodynamic sections specified for the outboard blade PART when the blade was created. If the blade has only one part, it is this one.

Executing either panel will generate aerodynamic GFORCE elements all along the selected blade at the aerodynamics center markers, each with the correct parameter list for the AeroDyn GFOSUB automatically inserted. Again, the user is referred to the AeroDyn documentation in Appendix H for more complete details on the implementation of the aerodynamics.

#### 6.2.1 Special AeroDyn MARKERs

To work properly, AeroDyn requires that a few extra, specially positioned and numbered MARKERs exist in the turbine model, along with a SENSOR element. **ADAMS/WT 2.0 does not create these automatically, you must manually add them to your model.**

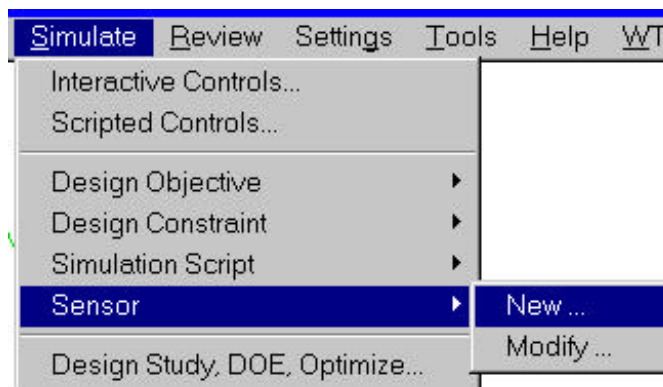
Usually, you would do this through the old-style panels available from the 8.X menu. For your convenience, the necessary information from the AeroDyn documentation in Appendix H is also summarized here.

##### Low-Speed Shaft Markers

ADAMS/Solver IDs = 305# where # is the blade number. Each MARKER must be on the low-speed shaft and have its z-axis along the nominal shaft axis of rotation and its x-axis in the plane formed by the low-speed shaft and the blade. The angles between each MARKER and *nac\_center* MARKER are considered as the blades' azimuth angles inside AeroDyn.

##### SENSOR

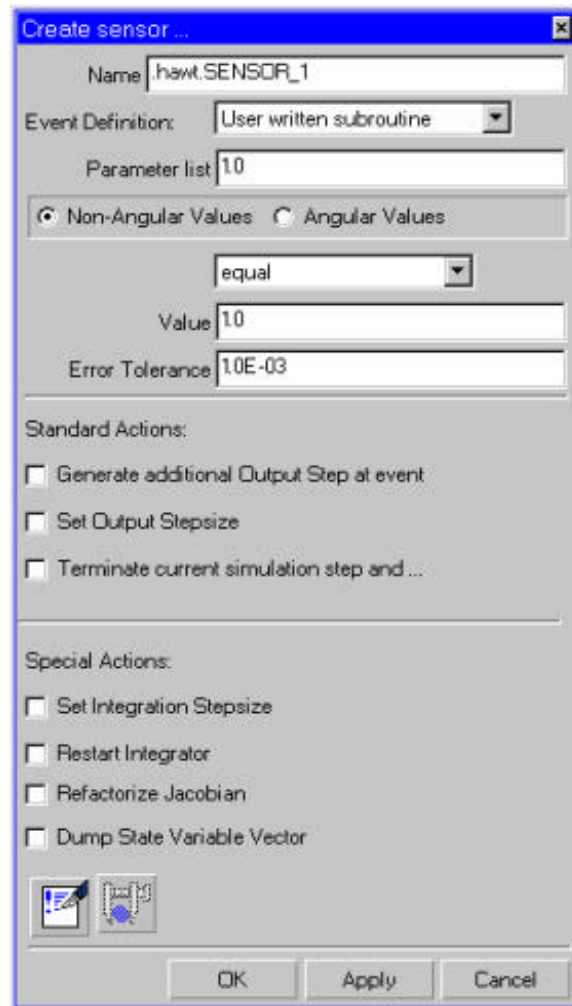
The AeroDyn aerodynamics use a dummy SENSOR to keep track of when a successful integration step has been taken. The SENSOR is added through the ADAMS/View panel found under SIMULATE / SENSOR menu.



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For simplicity, the panel and the correct input values are shown here:



### 6.3 Induced Inflow

The same approach that ADAMS/WT uses for the wind, i.e. a dummy VFORCE, can be used to add induced inflow effects to a model when using simple aerodynamic force elements for airloads. Of course, the AeroDyn routines include this effect automatically. Still, with induced inflow added, the simpler aerodynamics are a reasonable starting point for initial studies of a rotor configuration before later switching over to the more advanced AeroDyn routines. The simple aerodynamic forces run many times faster than the AeroDyn forces.

Adding inflow effects is not automated in ADAMS/WT and requires somewhat more familiarity with ADAMS/View than is required for the rest of WT. The following description is meant only as an outline of the methodology. There are three basic steps to adding induced inflow to a model with ADAMS/WT's simple aerodynamics:

1. You must create a differential equation to approximate the net thrust load.
2. You must create a dummy inflow VFORCE along the shaft axis whose z-axis component equals the inflow velocity.
3. You must modify either all the simple aerodynamic force element velocity VARIABLES to include that velocity, or, in the special case of uniform inflow, you may choose to modify the *wind* VFORCE instead.

The ADAMS/Solver DIFF differential equation element used to get rotor thrust is very simple, the function having the form:

$$dT/dt = (1/\tau) \cdot (T - lss\_bearing\_reaction)$$

This approach is used to smooth the JOINT reaction load, which tends to be numerically jerky in ADAMS, and can also be used for dynamic inflow by setting the time constant,  $\tau$ , appropriately. Note that this equation uses net thrust load, however, instead of the more correct aerodynamic thrust load.

The dummy VFORCE, which we can call *inflow*, should have its I marker's z-axis parallel to the shaft axis. Its J part should be rigidly attached (fixed joint) to the I part so that the net reaction load in the force is zero. Typically, the *nac\_center* MARKER and *stator* PART are used. The FX and FY function expressions are set to zero and the FZ expression is the standard algebraic relation for induced inflow:

$$F_z = \text{sqrt}(T/2\rho A)$$

where T is the value of the thrust DIFF,  $\rho$  is the air density and A is the rotor area. Note that with this approach, the induced inflow will always be along the shaft axis.

When modifying the Vy\_ and Vz\_ VARIABLES or the *wind* dummy VFORCE to include this additional velocity, you should carefully follow the method used for the *wind*. With some cautious macro programming, you can change all the VARIABLES at one time using an ADAMS/View macro. Note also that with some “inventive” use of ADAMS function expressions and references to other PARTs in the model, this same approach could be used to include radially-dependent induced inflow, vertical wind shear or even tower shadow.

(Note: If you have done this, we would very much like to include it in the next release of ADAMS/WT! Please send your example code to Andy Elliott as [aelli@adams.com](mailto:aelli@adams.com))